Diode power detector X-parameters™ model extraction using LSNA-based measurement system

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A study is presented on the problems that may arise when characterising low frequency device behaviour with a large signal network analyser (LSNA)-based measurement system. A diode power detector has been measured and, for the first time, an X-parameters based detector model was extracted from measurements. Difficulties measuring the detector output voltage dependence with baseband impedances, especially when those impedances showed resonant effects, were observed and a method to overcome the problems encountered is presented. The measurement-based detector X-parameters model demonstrated its usefulness to predict power detector behaviour under two-tone excitations and complex loads.

Introduction: Diode power probes have been used successfully for many years for high-speed power measurements, when the measured signal is a single sinusoid [1, 2]. In recent works [3, 4] it has been demonstrated that calibrating a diode-based power probe with a single-tone signal does not guarantee accurate detector calibration for complex signals. It was identified that this is related to long-term memory effects caused by the detector baseband impedances. Thus, the detector output DC voltage may vary depending on the RF input signal bandwidth.

In [4], an X-parameters model for diode power probes was proposed, which will be extended in the future for calibration purposes with modulated signals. In [4], this model was extracted from simulated data. DC measurements were used to validate the detector behaviour.

In this Letter, a method to perform the required measurements to extract and validate an X-parameters model for power probes using an large signal network analyser (LSNA)-based measurement system, is proposed. Difficulties encountered and possible solutions are discussed.

Power probe X-parameters model: In the X-parameters model proposed in [4] the detector output voltage is modelled by (1), where V_2 is the total voltage modelled at the detector's output when a certain RLC load is connected. $X_2^v(.)$ is the X-parameter that represents the DC voltage measured at the output under large-signal operating conditions and 50 Ω. $X^z_{2,2m11}(.)$ and $X^z_{2,2m22}(.)$ are the X-parameters providing the small signal contribution to the DC voltage at port 2 when a small signal at IF = (ω_2-ω_1) and 2IF is applied, respectively, to the output. Γ_{2m11}, Γ_{2m22}, Γ_{2m11} and Γ_{2m22} are the output reflection coefficients and output waves obtained at IF and 2IF, at the actual detector loading conditions. A_{110} and A_{101} are the large-signal incident waves at port 1 at ω_1 and ω_2, respectively, B_w is the two-tone spacing and I_{DC}, in this case is set to 0 (a zero bias Schottky diode was used).

$$\begin{aligned} V_2 = {} & X_2^v(|A_{(110)}|,\ |A_{(101)}|,\ Bw,\ I_{DC}) \\ & + \mathrm{Re}(X^z_{2,2m11}(|A_{(110)}|,\ |A_{(101)}|,\ Bw,\ I_{DC})\Gamma_{2m11}B_{2m11} \\ & + X^z_{2,2m22}(|A_{(110)}|,\ |A_{(101)}|,\ Bw,\ I_{DC})\Gamma_{2m22}B_{2m22}) \end{aligned} \tag{1}$$

Model extraction and validation with LSNA-based measurement system: Extraction of X-parameters models for high-speed power probes from measurements requires a wide- or multi-bandwidth large-signal measurement system, since the input signal is a microwave frequency signal but the detector output includes DC and baseband signals. Thus, the measurement system must detect DC, LF and microwave signals under small- and large-signal excitations in the appropriate impedance space. In this Letter, for model extraction and validation, a 0.6–50 GHz Maury-NMDG LSNA-based measurement system was used This system has been extended with an LF (dynamic bias) module [5, 6] to measure LF signals in the frequency range from 10 kHz to 24 MHz. Fig. 1 shows a simplified schematic of this system.

At the LSNA input, an RF vectorial signal generator is used to generate a two-tone signal around 5.8 GHz. At the output, a diplexer is used to split the detector output signal between the RF and LF + DC paths. At the LF + DC path, an LF sensing module (SM) measures the LF signals. A bias tee is used to separate the DC and LF components. Different types of measurements were performed around 50 Ω for model extraction purposes, as detailed in [4], including the use of a small-signal tone applied at baseband frequencies (LF path) while the detector was excited by a large-signal microwave tone at its input. For model validation purposes, the detector was loaded by a RLC impedance placed in the LF path, as shown in Fig. 1.

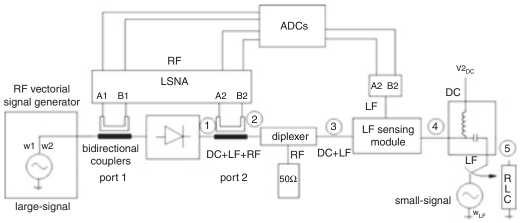

Fig. 1 *LSNA-based measurement system setup*

In [3] it was shown that the combination of the power detector and a certain RLC load produced a resonance at LF frequencies, thus making the detector DC output voltage vary with the two-tone frequency spacing. This effect was confirmed both in simulations, with a time domain model, and via DC measurements [4]. In the present Letter, the model was directly extracted and validated using LSNA measurements. But, as shown later, the LF system baseband impedance may affect the actual impedance space available and the accuracy of the extracted X-parameters model.

Results: Initially, the measured detector DC output voltage with the LSNA, and with the same RLC impedance used in [3], was unexpectedly invariant with the two-tone spacing. The measurement system was apparently masking the resonance effect produced by the RLC load. Hence, the detector was measured with the load alternatively connected at five different positions in the system, numbered from 1 to 5, in Fig. 1. Fig. 2 shows the corresponding measured detector DC output voltage. It can be seen that each component of the system affects not only the resulting resonance frequency, but also the detector output voltage at this frequency and those close to it. The more dramatic effects were produced when the LF SM was used as part of the system, practically masking the effect of the RLC impedance. This problem occurs due to the power detector's output impedance, which, when the RLC load is placed, is 40 KΩ at resonance, as seen in [4]. Thus, other elements connected in parallel to this load, may modify both the impedance and the baseband frequency resonance, as shown in [3] with a multimeter. These effects would not be important when, as it is usual, the detector output impedance is close to 50 Ω, but they cannot be neglected when it is above hundreds of ohms. The original LF SM, presents an impedance of 500 Ω, much lower than the case study detector's output impedance value, thus masking the RLC load.

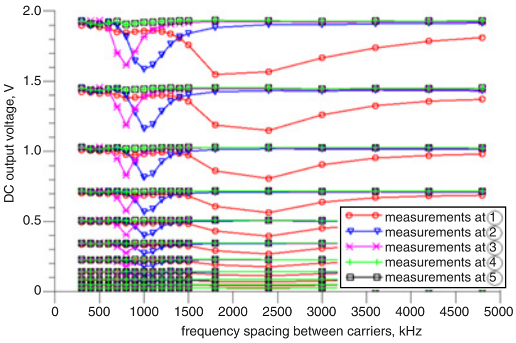

Fig. 2 *Measured power probe DC output voltage against two-tone spacing and input power (– 30 to 0 dBm) with different system configurations*

To accurately extract and verify the X-parameters model at LF frequencies, we tried to minimise the effects of the system components connected to the detector's output by replacing the LF SM by a new one, designed and fabricated by the authors at the University of Vigo. The new SM is similar to the NMDG one, but it includes larger resistances in parallel to present a 25 KΩ impedance. Figs. 3*a* and *b* show the measured DC voltage and B_2 at IF, respectively, with this new SM, when the RLC load is attached, and the original SM. With this new module it is possible to properly measure with the LSNA the influence of the impedance resonance on the detector output DC values.

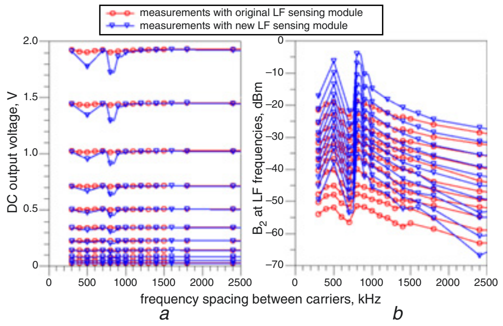

Fig. 3 *Power probe measurements with original and new LF sensing module*

a DC output voltage
b B_2 at the IF frequency

X-parameters model validation: Finally, since the measurement system is now, with the new LF SM, less able to affect the detector behaviour at baseband, it was possible to accurately extract and validate a suitable detector X-parameters model, as in [4], but now extracted only from measurements. Fig. 4 shows a comparison between measurements and X-parameters model simulations of the detector behaviour with the RLC load, showing the expected results.

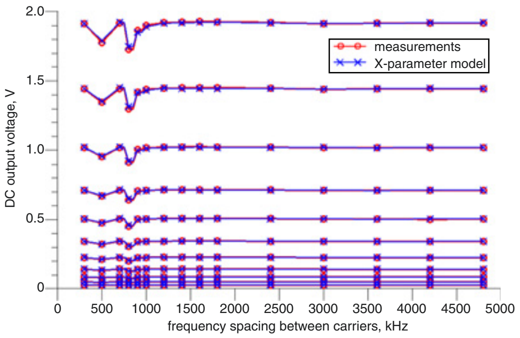

Fig. 4 *Measured and simulated power probe DC output voltage*

Conclusion: An LSNA-based measurement system has been presented that can allow for the measurement of LF X-parameters. Using this system, a diode power detector X-parameters model has been extracted from measurements, for the first time. A key development was to ensure that the system was able to effectively vary the measurement system LF impedance. The importance of placing a suitable LF SM is proved. Finally, the detector model was validated with measurements and its usefulness to predict power detector behaviour under two-tone excitations was demonstrated.

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One or more of the Figures in this Letter are available in colour online.

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References

1 Kanda, M.: ‘Standard probes for electromagnetic field measurements’, *IEEE Trans. Antennas Propog.*, 1993, **41**, (10), pp. 1349–1364
2 Ladbury, J.M., and Camell, D.G.: ‘Electrically short dipoles with a nonlinear load, a revisited analysis’, *IEEE Trans. Electromagn. Compat.*, 2002, **44**, (1), pp. 38–44
3 Gomes, H., Testera, A.R., Carvalho, N.B., Barciela, M.F, and Remley, K. A.: ‘Diode power probes measurements of wireless signals’, *IEEE Trans. Microw. Theory Tech.*, 2011, **59**, (4), pp. 987–997
4 Boaventura, A.S., Testera, A.R., Carvalho, N.B., and Barciela, M.F.: ‘Using X-parameters to model diode-based RF power probes’. Int. Microwave Symp., Baltimore, MD, USA, June 2011, pp. 1–4
5 Avolio, G., Pailloncy, G., Schreurs, D., Vanden Bossche, M., and Nauwelaers, B.: ‘Simultaneous measurement of high and low frequency response of non-linear microwave circuits’. ARFTG Microwave Measurements Symp., Portland, OR, USA, December 2008, pp. 79–84
6 http://www.nmdg.be/product_nm500.html